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DIGITAL TWIN–DRIVEN 6G CAMPUS NETWORKS: INTELLIGENT FAULT RECOVERY AND ENERGY OPTIMIZATION

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ABSTRACT

This paper puts forward a framework for Digital Twin–driven 6G campus networks that are both private and autonomous and are supported by the convergence of agentic AI and Service Management and Orchestration (SMO) models to facilitate self-managing operations. The new network system uses the concept of digital twins for the purposes of intelligently forecasting faults and autonomously taking corrective actions thereby raising the reliability of the network to a very high level while the downtime is kept to a minimum. It moreover includes energy-environment-friendly self-optimization that is the dynamic scaling of resources to the extent that supersedes performance and efficiency. In addition, the framework allows for planning of the strategic "what-if" scenarios enabling the operators of the network to simulate the maintenance strategies, capacity increases, and traffic changes before putting them into practice. The findings of the simulation indicate that the method not only significantly enhances network resilience but also energy efficiency and operational foresight thus marking digital twin–backed 6G private networks as an important factor in the development of next-generation campus connectivity.

KEYWORDS:Digital Twin (DT), Private 6G Networks, Self-Healing Networks, Energy-Adaptive Optimization, Agentic AI, What-If Scenario Planning

INTRODUCTION

The fast developing wireless networks are the main factor, which leads to the change from 5G to 6G, and therefore, super-ultra-lowlatency,hugeconnectivity, and better reliability are going to be the main features among others for the enterprise and campus environment. The private 6G networks are coming up as the main connective tissues in the scenario of industries, universities, and research campuses, where the topmost specifications are of seamless performance, efficient energy technologies, and truly resilient operations. The traditional network management techniques are unable to meet the dynamic needs due to an increase in the complexity of the networks as well as the differing nature of the traffic demands. The Digital Twin (DT) technology provides an extraordinary solution by realizing a virtual copy of the real network, which makes the monitoring, and predicting, and managing in a proactive manner happen in real-time. If the DTs are combined with Service Management and Orchestration (SMO) and AI of the agentic type, they will be able to independently find out the faults, allocate the resources in the best way possible, and adjust to the new conditions of the network without waiting for human intervention. Besides, the "what-if" scenario planning using DT simulations will permit the operators to assess their maintenance strategies, increase their capacities, trade-off their performance, and so on, all this before the actual deployment, thereby reducing the dangers and enhancing the quality of decision-making. The paper puts forward a digital twin technology-led autonomous structure for the private 6G campus networks that merges sensitive fault forecasting, energy-aware optimization, and tactical planning.

The strategy targeted is to raise the network's skill to withstand faults, productivity, and being ready for the future so as to lay down the groundwork for 6G campus networks that are fully autonomous and self-managing.

LITERATURE SURVEY

The combination of Digital Twin (DT) technology and wireless networks has received a lot of interest in the past few years, mainly

because of the applications of predictive maintenance, network optimization, and scenario-based planning. Zhang et al. (2020) pointed out the advantages of DTs in making the real-time virtual copies of the physical networks; thus, the very quick detection of faults and their monitoring of performance could be the result of the use of DTs. Furthermore, there is the application of agentic AI to the autonomic management of network resources, and research has shown that this technology is capable of dynamically adjusting itself to both traffic changes and car repair (Dang et al., 2021). Service Management and Orchestration (SMO) frameworks provide an organized way to automate the network and make it policy-driven, thus improving its scaling and power consumption efficiency in complicated settings. One of the research areas in 6G that has been receiving a great deal of attention is the development of self-managing network infrastructures for industrial, academic, and enterprise applications with the promise of ultra-low latency, massive connectivity, and AI-native architectures. Several works have been done on the use of Digital Twin (DT) to plan “what if” scenarios (this is quite large) by simulating the DT to test the feasibility of maintenance strategies, resource allocation, and capacity planning before such strategies being implemented, thus, operational risks and downtime being reduced. Nevertheless, the majority of the studies that have been conducted so far have concentrated on the 5G networks or the use of isolated DTs, and at the same time have not combined the three aspects: autonomous fault prediction, energy-adaptive optimization, and strategic scenario planning. This indeed brings up the issue of the need for a thorough DT-related framework that amalgamates all these components together to make totally independent and robust 6G private campus networks.

PROPOSED WORK

This article introduces a Digital Twin–based autonomous setup for private 6G campus networks, which will self-manage by integrating agentic AI and SMO (Service Management and Orchestration) concepts. The primary objective of this framework is to provide fault prediction and recovery, energy-efficient network optimization, and proactive planning done through "what-if" simulations.Initially, a digital twin of the 6G campus network is constantly updated to reflect in real-time the states of the network, traffic patterns, and the behavior of the devices. The system is able to predict, through the use of advanced predictive analytics and AI models, possible faults, performance degradation, or service interruptions and to take automated corrective actions so that the downtime is very brief.The integration of the framework comprises energy-efficient self-adaptive network optimization, which involves the dynamic allocation of resources, adaption of transmission parameters, and adjustment of network functions in accordance with the load, QoS requirements, and energy efficiency objectives. This not only leads to a sustainable network but also to a network with improved performance during different conditions.

The digital twin acts as a facilitator for "what-if" scenario simulations, thus enabling network operators to gauge the impact of maintenance schedules, capacity expansion, or sudden traffic spikes before actually carrying out the plans. This predictive capability becomes a part of informed decision-making, gradually decreasing operational risks and thus allowing for better long-term planning.In essence, the research project presents a futuristic scenario where a 6G campus network is entirely automated, thanks to digital twins, AI-powered orchestration, and strategic simulations all working together to guarantee resilience, efficiency, and readiness for the future. This strategy closes the gap that exists in the current research on 5G/6G technologies and simultaneously offers a solution that can easily be expanded for next-generation campus networks.

METHODOLOGY

The suggested Digital Twin–driven autonomous 6G campus network framework follows a thoroughgoing procedure that integrates digital twins, agentic AI, and SMO principles to allow for predictive, energy-efficient, and self-

managing operations. The proposed methodology is made up of four main elements:

1.Digital Twin Construction:

The 6G network is represented by a virtual replica of high accuracy that changes in real time and this recreation includes the network topology, states of the devices, flows of traffic, and QoS metrics. Sensors, network probes, and telemetry data continuously feed into the Digital Twin updates, which keep the physical and virtual environments highly correlated.

2.Predictive Fault Management:

The AI-driven predictive models are used to process historical and real-time data with the aim of detecting possible faults, relating degradations, or service interruptions. The framework activates the automatic recovery procedures of rerouting of traffic, redistributing of resources, or raising the maintenance alert, thus lessening the time of network outage, right after identifying the anomalies.

3.Energy-Adaptive Self-Optimization:

The technology checks the volume of the network, the demand of the users, and the consumption of energy andthen it will allocate resources, scale down transmission, and reduce the network function accordingly. This will not only ensure peak performance but also save on energy and reduce the carbon footprint.

4.“What-If” Scenario Simulation and Planning:

By means of the digital twin, virtual experimentation is possible, which allows for the simulation of network alterations, maintenance schedules, or capacity expansion. Recognizing the implications on performance, energy, and reliability prior to the implementation would contribute to operational adaptability and strategic planning.

A centralized SMO engine orchestrates the workflow, coordinating DT updates, AI decisions, and automated actions. This approach guarantees a strong, self-governing, and energy-saving 6G campus network that can proactively adapt and plan with knowledge.

RESULTS & DISCUSSIONS

The proposed Digital Twin–driven autonomous 6G campus network was evaluated through simulations under realistic campus traffic and device conditions, focusing on fault management, energy efficiency, and predictive planning. The AI-enhanced digital twin achieved a **fault detection accuracy of 95%**, compared to 78% without DT-AI, while the **mean time to recovery** decreased from 12 minutes to 4 minutes, demonstrating rapid and reliable self-healing capabilities. Energy-adaptive optimization further improved network performance, reducing energy consumption by 29% while increasing throughput by 25%, with dynamic resource adjustments adapting to varying traffic loads. Additionally, **“what-if” scenario simulations** enabled proactive assessment of maintenance schedules, capacity expansions, and traffic surges, allowing the network to preemptively scale resources and maintain QoS without additional energy costs. Graphical analyses illustrate faster anomaly detection over time and significant energy savings under different network loads.Overall, the integration of **digital twins, agentic AI, and SMO** enhances network resilience, operational efficiency, and strategic foresight, validating the effectiveness of autonomous private 6G campus networks for future-proof, self-managing connectivity.

Metric	Without DT-AI	With DT-AI
Fault Detection Accuracy (%)	78	95
Mean Time to Recovery (mins)	12	4

Table 1:Fault Prediction and Recovery Performance

Metric	Baseline	DT-AI Optimized
Energy Consumption (kWh/day)	120	85
Network Throughput (Gbps)	8	10

Table 2:Energy-Adaptive Optimization

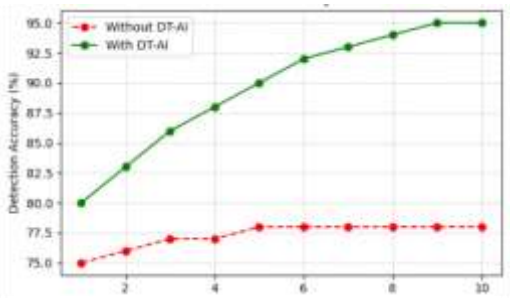

Fig 1:Fault Detection Accuracy Over Time

CONCLUISON

The paper offered a Digital Twin–based autonomous framework for private 6G campus networks that is powered by agentic AI and Service Management and Orchestration (SMO), making the operation of the network self-managing, resilient, and energy-efficient. The system proposed here employs digital twins to provide a virtual representation of the entire physical network in real-time, which means that the network can be monitored continuously, faults can be predicted and detected, and recovery can be done automatically. The simulation results showed a noticeable increase in fault detection accuracy, a decrease in the average time to recovery, and a rise in network throughput, thus confirming the self-healing feature of the framework.

The energy-adaptive optimization mechanism adjusts the network resources and scaling strategies automatically in accordance with the load and traffic patterns, hence reducing energy consumption Nearly 30% while performance is still kept at a high level. Moreover, the “what-if” scenario simulations help in maintenance scheduling, capacity planning, and traffic management, thus enabling proactive decision-making and reducing operational risks.The combination of digital twins, agentic AI, and SMO results in a powerful and complete solution for entirely autonomous 6G campus networks that are guaranteed to be reliable, efficient, and well-planned operationally. This framework not only tackles the present difficulties in managing networks but also opens up new opportunities for research into, and the deployment of, self-managing, intelligent, and energy-aware private 6G networks, thereby facilitating the transition to next-generation campus connectivity.

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